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16. ABSTRACT

The objective of this study was to determine how broadly applicable an empirical mathematical model, developed previously, would be in predicting final effluent coliform numbers as a function of ozone transferred and the effluent demand. A prediction equation was tested on six effluents from wastewater treatment plants in greater Cincinnati. Results indicated that the empirical model predicted with reasonable accuracy the total coliform density in four of the six plant effluents. One of the two not conforming accurately likely would have, if it had received dose levels more closely consistent with its water quality than was originally judged. The one plant effluent not conforming at all to the model's predictions had a high concentration of industrial components, which exerted a substantially different rate of ozone demand than the strictly municipal effluents. It was concluded that the model could be useful for design sizing of ozonation equipment if the treatment plant for which it is designed will be reasonably free of industrial influents.

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Application of an ozone disinfection model for municipal wastewater effluents

Mark C. Meckes, Albert D Venosa, James W. Evans

Ozone disinfection of municipal wastewater effluents has been demonstrated to be an effective method of achieving bacteriological discharge standards.[1] However, ozone reacts non-selectively with oxidizable materials and it is difficult to predict the amount of applied ozone needed to meet such standards reliably.

In 1977, Scaccia and Rosen[2] demonstrated that the disinfection efficiency of ozone could be related to the amount of ozone transferred into the process water regardless of the contactor type. Venosa *et al.* demonstrated in 1978[3] that the amount of ozone transferred to a municipal effluent was directly related to the reduction in the number of coliforms entering the disinfection systems. Stover and Jarnis[4] also related transferred ozone to effluent coliform content and found that nitrified effluent and filtered nutrified effluent required less ozone transfer than conventional secondary effluent to achieve a given coliform standard. Given and Smith[5] developed a mathematical model by multiple regression analysis and indicated that survival of indicator organisms could be predicted by knowing the amount of ozone transferred and the 5-day biochemical oxygen demand (BOD_5) of the secondary effluent. An empirical model[6] similar to that of Given and Smith's[5] indicated that effluent coliform numbers could be predicted from the amount of ozone transferred and the total chemical oxygen demand (TCOD) of the effluent. Clearly, there is considerable evidence indicating that disinfection with ozone is a function of the adsorbed dose (ozone transferred) and the effluent's ozone demand. The applied ozone dose is less easily correlated because the transfer efficiency is a function of the way in which ozone is applied to the effluent.[3]

In view of the above relationships it would be beneficial for system design purposes to determine how broadly applicable an empirical mathematical model would be in predicting final effluent coliform numbers as a function of the ozone transferred and the effluent demand. A prediction equation[6] was tested on six effluents from wastewater treatment plants in greater Cincinnati.

EXPERIMENTAL

Sources of secondary effluent. Secondary effluent was obtained from six different sources: the Fairfield Wastewater Treatment Plant (FP), Fairfield, Ohio; the Indian Creek Wastewater Treatment Plant (ICP), Cincinnati, Ohio; the Loveland Wastewater Treatment Plant (LP), Loveland, Ohio; the Mill Creek Wastewater Treatment Plant (MLC), Cincinnati, Ohio; the Muddy Creek Wastewater Treatment Plant (MDC), Cincinnati, Ohio; and the Sycamore Wastewater Treatment Plant (SP), Cincinnati, Ohio. FP, MLC, and MDC are conventional activated sludge treatment plants. LP and SP are contact stabilization plants, and ICP uses rotating biological contactors to treat municipal wastewater. Of the six treatment plants, five receive raw wastewater of municipal origin. The sixth, MLC, receives wastewater with a high concentration of industrial wastes (about 50% by weight). Major contributors to the industrial components include household manufacturing wastes, cosmetics wastes, dyes, inks, pigments, meat packing wastes, distillery wastes, and chemical company wastes.

Coliform densities in ozonated municipal effluents can be confidently predicted for plants not receiving industrial wastes.

Approximately 20 m^3 of a given effluent was collected in a tank truck on the day of an experiment or the day before and transported to the U.S. Environmental Protection Agency's (EPA) Test and Evaluation Facility, located adjacent to the MLC plant. When an effluent was collected the day before an experiment, it was recirculated in the tank truck for a minimum of 1 hour before the experiment.

Ozone generation. Ozone was generated from oxygen in a plate-type, corona discharge generator. Oxygen flow to the ozonator was maintained at a constant 33 L/min. Liquid flow was a constant 75 L/min, resulting in a gas-

to-liquid flow ratio of 0.44. Changes in the applied dose were accomplished by varying the concentration of ozone in the gas flow (by increasing or decreasing the power applied to the generator).

Ozone contactor. The ozone contactor was a bubble diffuser with 3 columns in series. Its design and operating characteristics are described elsewhere.[6]

Sampling. All effluent samples were grab samples analyzed for total and soluble chemical oxygen demand (TCOD and SCOD), total organic carbon (TOC), total suspended solids (TSS), and turbidity by "Standard Methods."[7] Total Kjeldahl nitrogen (TKN), ammonium nitrogen (NH_4^+-N), and nitrite-nitrogen (NO_2^--N) were measured according to "Methods for Chemical Analysis of Wastes,"[8] and nitrate-nitrogen (NO_3^--N) according to Kamphake, Hannah, and Cohen.[9] Ozone concentration in the inlet and exhaust gases was periodically determined iodometrically[10] and continuously by ultraviolet adsorption analyzers. Ozone residual (as total residual oxidant) was measured by the reverse titration standard iodometric method for chlorine residual[7] using the amperometric end point.

Samples collected for bacteriological analysis were assayed for total and fecal coliforms by the standard membrane filtration (MF) method,[7] using 0.45-μm GN-6 membrane filters.

Experimental design. The approach chosen was based on the hypothesis that the empirical relationship presented previously[6] predicts, with a reasonable degree of accuracy, the total coliform density of a municipal wastewater effluent following treatment with ozone. The relationship is:

$$TC = 24\,000(TCOD)^{0.04}/T^{4.58} \qquad (1)$$

where

TC = total coliforms/100 mL after ozonation, and
T = ozone transferred, mg/L.

If one knows the TCOD of an effluent, one may be able to predict the final coliform density at various levels of adsorbed ozone. To test this hypothesis six local treatment plants were grouped according to the mean TCOD concentrations of their effluents. Before the ozonation experiments were conducted, nine effluent samples from each of the treatment plants were collected over a 3-week period and measured for TCOD. The mean TCOD levels were then compared and like plants grouped accordingly. Three groupings resulted: a low TCOD group (three plants), a medium TCOD group (two plants), and a high TCOD group (one plant).

By rearranging Equation 1 and solving for T at five different total coliform levels, five absorbed ozone levels were computed for each of the three groupings. The applied dose levels needed to achieve the five absorbed ozone levels were calculated by assuming an average transfer efficiency of 90% (previous data[6] had indicated that 90% transfer efficiencies were possible in the bubble diffuser contactor, with oxygen as the feed gas, at gas-to-liquid flow ratios of ≤ 0.5). The resulting five relative dose levels for each of the treatment plant groupings are presented in Table 1. The five applied doses (labeled A through E) are relative in the sense that each one theoretically yields equivalent coliform densities consistent with effluent quality as long as dose is varied by changing the ozone concentration in the inlet gas stream and maintaining constant gas-to-liquid flow ratio. If the empirical model were a good predictor, dose A would yield the same total coliform density in all effluents, dose B would yield a lower number in all effluents, and so on.

By grouping the plant effluents in the above fashion, it would facilitate further analysis of factors affecting ozone disinfection, if there were a significant difference between effluent sources with respect to post-ozonation coliform densities. To minimize any trend in wastewater effluent quality in a given day, the design was balanced so that each dose level occurred the same number of times at each time of day. The five sets of observations were taken over a period of approximately 4 hours. Plant effluents were collected five times from each of the six plants according to a randomized collection schedule.

RESULTS

Wastewater quality. Table 2 summarizes the physical-chemical and bacteriological characteristics of the effluent sources prior to ozonation. An inspection of the mean TCOD values reveals that effluent source LP should have been grouped to receive the same applied ozone doses as FP and SP, rather than the lower dosages used for ICP and MDC. This misgrouping of the LP effluent was caused because earlier samplings had indicated a mean TCOD value for this effluent comparable to ICP and MDC effluents. We did not attempt to readjust the doses applied to the LP effluent as the study

Table 1—Relative dose scheme for the three treatment plant groupings used in the study.

Relative dose	Theoretical $\log_{10}$ total coliform density	Actual dose, mg/L		
		group I[a]	group II[b]	group III[c]
A	5.0	1.3	2.3	5.1
B	4.0	3.3	5.1	10.0
C	3.0	5.0	7.6	15.0
D	2.0	6.7	9.8	20.5
E	1.0	8.6	12.4	25.1

[a] Effluent sources ICP, LP, and MDC.
[b] Effluent sources FP and SP.
[c] Effluent source MLC.

Table 2—Secondary effluent characteristics of the six treatment plants prior to ozonation.

Parameter	Mean concentration, mg/L or as indicated in:					
	Sycamore (SP)	Fairfield (FP)	Loveland (LP)	Indian Creek (ICP)	Muddy Creek (MDC)	Mill Creek (MLC)
TCOD	38	39	39	26	29	74
TOC	8.3	5.6	6.8	5.2	5.0	19.6
TSS	8.6	4.1	8.3	9.2	3.8	11.5
TKN	7.5	5.3	13.8	1.7	1.5	18.7
NH_4^+-N	5.6	4.3	11.7	0.3	0.8	19.3
NO_2^--N	0.5	0.6	0.5	0.2	0.2	0.6
NO_3^--N	2.5	7.5	0.1	7.5	6.0	0.2
Turbidity, JTU	7.5	2.5	13.8	1.7	1.5	18.7
pH (range)	(7.2–7.9)	(7.3–8.3)	(7.4–8.2)	(7.9–8.4)	(7.3–8.1)	(7.4–7.9)
$\log_{10}$TC/100 mL	6.43	5.41	6.56	5.59	5.41	5.72
$\log_{10}$FC/100 mL	5.67	4.69	5.80	4.43	4.59	4.75

progressed to determine the effect the improper grouping of this effluent source would have had on the overall analysis.

Effluent differences. An analysis of variance (ANOVA) of the $\log_{10}$ total and fecal coliform data after ozonation indicated that significant differences existed among the various sources of secondary effluent. This suggested that coliform densities in the six effluents were not equivalent following ozonation. Hence, Equation 1 apparently did not predict those levels accurately. The Duncan Multiple Range (DMR) test was used to determine which effluent sources yielded significantly different coliform results. The test revealed two important findings: coliform levels in the LP effluent were higher than predicted because of the misgrouping mentioned above; and, coliform levels in the Mill Creek effluent were much higher than normal because of the high concentration of nonbiodegradable industrial constituents present in the effluent. The latter point will be discussed later. In Figure 1 the mean log total coliform levels in the five domestic effluent sources are plotted against the five relative ozone doses used in the test. Had the LP effluent been grouped with effluent sources FP and SP and received the same applied ozone dose, the response in that effluent would have undoubtedly been closer to the other four.

To display the coliform response on an absolute rather than relative ozone dose basis, total coliform numbers were plotted as a function of actual applied dose (Figure 2). The data were linearized by graphing on double log paper. Upon examining Figure 2, several important points become evident. First, there are clearly two distinct sets of data: one belonging to a group of three treatment plants, the other belonging to a group of two. The dose response in the LP effluent definitely behaved like that in the SP and FP effluents. Second, the initial total and fecal coliform levels in the FP effluent were equivalent to the ICP and MDC effluents (Table 2). Yet, the dose response of the FP effluent was equivalent to the LP and SP effluents. The latter three all had the same TCOD content prior to ozonation. Thus, even though the initial coliform levels in the FP effluent were one order of magnitude lower than those in the LP and SP effluents, the dose response was the same.

To demonstrate the ability of Equation 1 to predict the total coliform density in an ozonated municipal effluent, the predicted total coliform density was calculated from the observed TCOD and T data for each observation. The observed and predicted dose response relationships for each effluent source are presented in Figures 3a to 3f. Each point represents the mean of five observations. The model predicted accurately the total coliform density in the ozonated effluents from ICP and MDC (Figures 3c, d). Both these effluent sources were relatively low in TCOD (26 and 29 mg/L, respectively). The model slightly underestimated, but still adequately

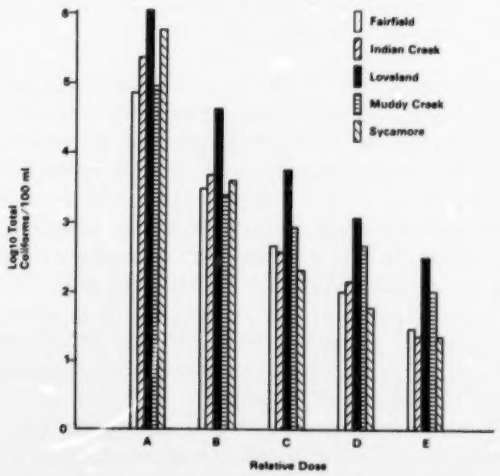

Figure 1—Effect of relative ozone dose on $\log_{10}$ total coliforms/100 mL for five municipal effluents. Each level is the mean of five observations.

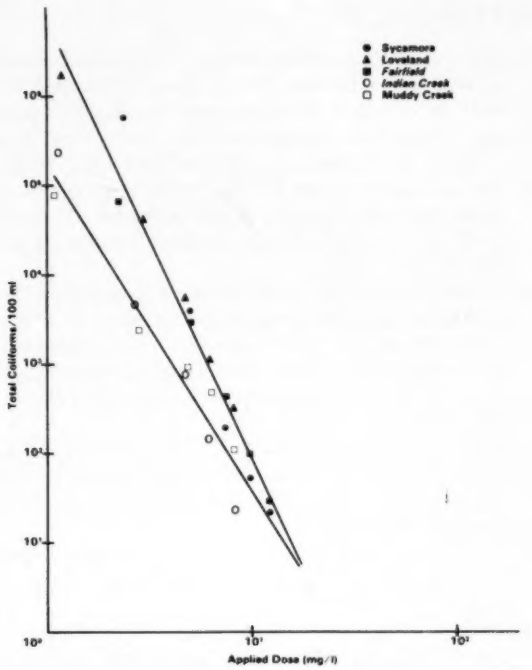

Figure 2—Effect of applied ozone dose on $\log_{10}$ total coliforms/ 100 mL for five municipal effluents grouped by comparable mean TCOD values. Each point is the mean of five observations.

predicted, total coliform densities in ozonated effluents from FP, LP, and SP (Figures 3a, b, e). These three effluent sources had an approximately equal mean TCOD level (39 mg/L), which was moderately above the levels in the ICP and MDC effluents. The MLC effluent (Figure 3f) was atypical because of the high concentration of industrial components in its influent, as mentioned earlier and discussed further below.

DISCUSSION

Chemical oxygen demand is defined in "Standard Methods" as a measure of the oxygen equivalent of the organic matter content of a sample susceptible to oxidation by a strong oxidizing agent, usually potassium dichromate. Not all reducing agents are measured in the COD test, however, and the stoichiometries of reactions between dichromate and susceptible organic compounds are complex and varied.

Ozone, too, is a strong oxidizing agent. Because COD is a measure of the reducing capacity of a water or wastewater sample, it follows that effluents high in COD may require more ozone applied to achieve a given level of coliforms than effluents with lower CODs. As with dichromate, the stoichiometries of reactions between ozone and COD constituents are also highly variable. Because wastewaters themselves vary extensively in COD, one would not expect to find a consistent empirical correlation between COD and ozone demand.

The mathematical model developed empirically in a previous phase of work[6] predicted with reasonable accuracy the total coliform density in four of six treatment plants tested. Had the LP effluent been grouped with the FP and SP effluents at the beginning, its coliform content, too, would likely have been predicted by the model. The only effluent that did not conform adequately to the model's predictions was from the MLC plant. As stated previously, the latter effluent contained high concentrations of chemical components from a wide variety of industrial inputs. This resulted in a higher than normal COD. More importantly, the compounds exerting the COD apparently had significantly different ozone demands than those of the other five treatment plants, which received very little industrial waste. Consequently, the empirical model, which was developed on an effluent from a treatment plant receiving primarily domestic wastes, failed to predict the proper coliform levels after ozonation. This is not surprising, and merely points out that an empirical model is never universally applicable.

However, if a treatment plant being designed will be reasonably free of industrial influents, the model may be useful for the proper sizing of ozonation equipment. As shown in Figure 2, prior knowledge of the COD and ozone transfer properties of a given effluent appear helpful for that purpose. Restrictive assumptions that must be used in the application of the model are: ozone is

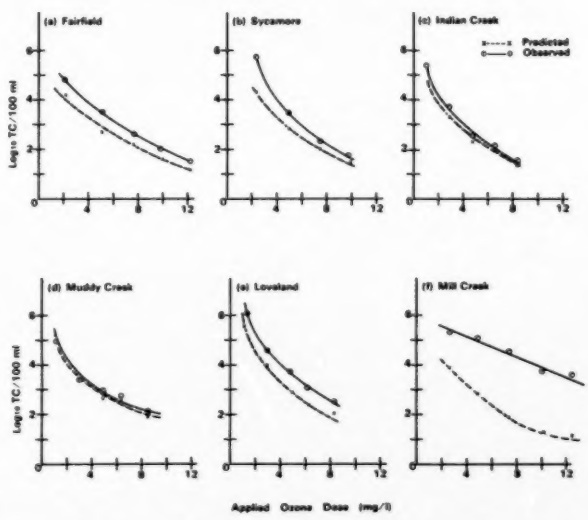

Figure 3—Comparison of observed and predicted total coliform (TC) densities with respect to applied ozone dose for each effluent source tested. Each point is the mean of five observations.

generated from pure oxygen; the gas-to-liquid flow ratio is ≤0.44; a bubble diffuser contactor is used and operated in countercurrent flow; and dose is varied by changing the power input to the generator while maintaining a constant gas-liquid flow ratio.

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REFERENCES

1. Rakness, K. L., and Hegg, B. A., "Field Scale Evaluation of Wastewater Disinfection by Ozone Generated From Air." In "Progress in Wastewater Disinfection Technology." *Proc. Nat. Symp. Cincinnati, Ohio, Sept. 18–20, 1978.* A. D. Venosa, (Ed.), EPA-600/9-79-018 (1979).
2. Scaccia, C., and Rosen, H. M., "Ozone Contacting: What is the Answer?." Paper presented at the Int. Ozone Inst. Symp. on Advanced Ozone Technol., Toronto, Ontario, Canada (Nov. 1977).
3. Venosa, A. D., *et al.*, "Comparative Efficiencies of Ozone Utilization and Microorganism Reduction in Different Ozone Contactors." In "Progress in Wastewater Disinfection Technology." *Proc. Nat. Symp. Cincinnati, Ohio, Sept. 18–20, 1978.* A. D. Venosa, (Ed.), EPA-600/9-79-018 (1979).
4. Stover, E. L., and Jarnis, R. N., "Engineering and Economic Aspects of Wastewater Disinfection with Ozone Under Stringent Bacteriological Standards." *Ozone: Sci. and Eng.*, **2**, 159 (1980).
5. Given, P. W., and Smith, D. W., "Disinfection of Dilute, Low-Temperature Wastewater Using Ozone." *Ozone: Sci. and Eng.*, **1**, 91 (1979).
6. Venosa, A. D., *et al.*, "Disinfection of Filtered and Unfiltered Secondary Effluent in Two Ozone Contactors." *Environ. Int.*, **4**, 299 (1980).
7. "Standard Methods for Examination of Water and Wastewater." 14th Ed., Amer. Pub. Health Assoc., Washington, D. C. (1975).
8. Methods Development and Quality Assurance Research Laboratory, "Methods for Chemical Analysis of Water and Wastes." EPA-625/6-74-003, U. S. Environ. Prot. Agency, Cincinnati, Ohio (1974).
9. Kamphake, L. J., *et al.*, "Automated Analysis for Nitrate by Hydrazine Reduction." *Water Res.*, **1**, 205 (1967).
10. Birdsall, C. M., *et al.*, "Iodemetric Determination of Ozone." *Anal. Chem.*, **24**, 662 (1952).